

Stemflow Variability in Tropical Lowland Forest Landscape Transformation System: Case Study at Jambi Province, Indonesia

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Abstract

Land cover change may cause change on the hydrological function of an area, particularly on the distribution of rainfall that reach land surface. This study describes the characteristic of stemflow occurred within 4 ecosystems in Jambi, namely logged forest, jungle rubber, rubber plantation, and oil palm plantation. The main objective of the study was to measure the variability of stemflow in those 4 ecosystems. The main data used were rainfall and stemflow data that were directly measured for 5 months. The derived regression equation model showed that stemflow increase with rainfall depth. It was shown that values of stemflow amongs plantation types was varied indicated by the difference of its regression coefficients, as well as variations of the rainfall at the same transformation type. The percentage of stemflow to rainfall was ranging from 0.04–0.21% for rubber, 0.10–0.38% for jungle rubber, 0.28–0.54% for forest, and 0.84–3.07% for oil palm. The oil palm provided the highest stemflow volume compared to other land cover type. The uniqueness of oil palm canopy may cause the drainage of water from the canopy to the main stem that indicated by highest stemflow funneling ratio value. Rainfall significantly affected the amount of stemflow compared with the characteristics of the plant.

Keywords: forest transformation, land cover change, stemflow variability, stemflow funnelling ratio

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Introduction

Conversion of forests into other land uses has become a major issue in Indonesia, which causes a decline in forest cover (Romijn *et al.* 2013), especially natural forests on Sumatra Island, which is converted into oil palm plantations (Broich *et al.* 2011) and rubber plantations (Miyamoto 2006). During the past 10 years, oil palm plantations in Indonesia has doubled from 4.16 million ha in 2000 to 8.25 million ha in 2009, as well as the extensive rubber plantations during this period has increased by 62,849 ha from area 3,372,421 ha in 2000 to 3,435,270 ha in 2009 (MoA 2012). The decline of forest area and the increase of plantation area indicate a change in the water balance of the ecosystem (Nieschulze *et al.* 2009; Zhang *et al.* 2012; Dasanto *et al.* 2014). Land cover changes result in vegetation structure changes which affects the redistribution of rainfall through the soil surface (Zimmermann *et al.* 2008). The rain that falls on the vegetation will be retained by the plant canopy for a specific period. Most of this water evaporates and other reaches the ground because of dripping through the plant canopy or flowing down through the stem until reaching the base of the plant as stemflow. Part of rainfall that reaching at the ground

level is the sums of the throughfall and stemflow. Throughfall and stemflow controlled the distribution of rainfall that reach the ground level (Germer *et al.* 2010). Thus, the distribution of rainfall that goes into the ground is uneven. Past research has shown that stemflow gives high spatial variability (He *et al.* 2014), among species (Levia *et al.* 2010), vegetation communities (Carlyle-Moses *et al.* 2004; Bryant *et al.* 2005; Germer *et al.* 2006; Ziegler *et al.* 2009; Båse *et al.* 2012), and regions (Komatsu *et al.* 2008).

The rainfall distribution pattern as throughfall and stemflow affects the amount of water that may be infiltrated into soil (Shachnovich *et al.* 2008). Previous researches had been conducted in tropical mountain forests to identify the magnitude and variability of stemflow among some trees species (Herwitz 1986), the stem influence to the stemflow (Park & Cameron 2008), relationship between stemflow, and tree characteristics (Uber *et al.* 2014), the relationship among stemflow, rainfall, antecedent dry period, and area of stem bark (Hofhansl *et al.* 2012). Other researchers focus on the study of variability of stemflow with certain types of species (Opakunle 1989; Park & Cameron 2008; Siles *et al.* 2010). Although research on the interception and its parameters has

been done for decades, but its relationship with the vegetation has not fully understood yet (Dietz *et al.* 2006). Research on stemflow variability in landscape transformation of tropical lowland rainforest represented by logged forest, jungle rubber, rubber plantation, and oil palm plantation has not been done. The purpose of this study was to examine the stemflow variability of 4 land cover types of tropical lowland rainforest landscape transformation system namely logged forest, jungle rubber, rubber plantation, and oil palm plantation.

Methods

Description of study site This research was conducted at 4 types of land covers namely logged forest, jungle rubber, rubber plantation, and oil palm plantation. The sites of the study were administratively located in the of Bungku Village, Bajubang District, Batanghari Regency, Jambi Province. It is geographically located at coordinates E103°16'1.2" to E103°16'19.2" and S1°54'28,8" to S1°54'43.2". The locations were 50–100 m asl.

Research plot for forest cover was logged forest. Research plot for jungle rubber was the rubber trees planted by community in 1986 and then left without any management. Research plot for rubber plantation was monoculture rubber plantation planted by people in 1999 and carried out an intensive tapping once every 2 days. The research plots for oil palm plantation were monoculture oil palm plantation planted by community in 1999 (aged 14 years) and in 2005 (aged 8 years). Annual rainfall during the period 2001–2012 which were measured in the oil palm plantation of PT Asiatic Persada showed that annual rainfalls ranged 2,154–3,451 mm, with average of 2,475 mm year⁻¹. The mean of annual rainy days in the study area was 128 days (PT Asiatic Persada 2013).

Variability of stemflow was obtained by analyzing the parameters of stemflow. The parameters of stem flow calculation were:

- 1 Stemflow yield (Sy), of which stemflow volume deposited in a container (ℓ) (Germer *et al.* 2010).
- 2 Stemflow depth (Sd), which was defined as stemflow per area of collectors (mm). The stemflow depth (Germer *et al.* 2010) is formulated in Equation [1]:

$$Sd = Sy/A \quad [1]$$

note:

Sd = stemflow depth (mm)

Sy = stemflow volume (ℓ)

A = canopy area projection (m²)

- 3 Stemflow rate (Sr), stemflow rate indicates the volume of rainfall reaching the soil surface through stemflow per mm of rainfall, calculated using Equation [2] (Germer *et al.* 2010):

$$Sr = Sy/R \quad [2]$$

note:

Sr = stemflow rate (ℓ mm⁻¹)

Sy = stemflow volume (ℓ)

R = rainfall depth (mm).

- 4 Stemflow funneling ratio (SFR), which according to Herwitz (1986) is defined as the flow-per-square rod collector normalized using rainfall depth

(dimensionless), calculated by Equation [3]:

$$SFR = Sy/RB \quad [3]$$

note:

SFR = stemflow funneling ratio

Sy = stemflow volume (ℓ)

R = rainfall depth (mm)

B = stem basal area (m²)

The SFR shows the ratio between the volume of rainfall that flows into the base of the plant or tree trunks at certain diameter and the volume of rainfall that captured by the equal diameter rain gauge placed in an open area. SFR measures the impact of specific vegetation on redistribution and accumulation of rainfall (Garcia-Estringana *et al.* 2010).

Stemflow measurements were carried out in November 2012 to March 2013. Measurements were performed on 4 plants of oil palm (*Elaeis guineensis* Jacq.) in oil palm plantations namely OP1, OP2, OP3, and OP4, 6 sample trees in the rubber plantation namely R1, R2, R3, R4, R5 (*Hevea brasiliensis*), and R6 (*Archidendron pauciflorum*), 2 sample trees in the jungle rubber namely JR1 (*Hevea brasiliensis*) and JR2 (*Macaranga* sp.), and 2 trees in the logged forest namely F1 and F2 (*Litsea* sp.). The stemflow measurement was done every rainy day. Tools to measure the stemflow of oil palm were zincs plate that was inserted into the palm fronds and sealed with silicone to prevent leaks. After zincs plate was inserted properly on the oil palm trunks, the bottoms side then was connected to a jerry can containers which are made by using multi-slot divider method. The first container is given 11 holes and one of them was connected to the second jerry can so that the total capacity reaches 288 ℓ. Stemflow measurements on sample trees in the logged forest, jungle rubber, and rubber plantation were conducted by strapping a plastic hose which had been split and then nailed to the trunk to be stuck. Affixed hose was then sealed with a smooth silicone on its stick to prevent leakage. Finally, at the bottom of the hose was connected to the jerry can containers. Installation of stemflow measurement tool is shown in Figure 1.

Rainfall measurement was done every day by using Ombrometer Rainfall Gauge having a diameter of 14 cm. Two rainfall gauges were placed in an open area around the plot of stemflow measurements and another one was placed above the canopy of oil palm with a height of 6 m above ground level. Rainfall data of rainfall gauges in 3 locations were then averaged. Minimum daily rainfall used in the analysis was the depth of 0.5 mm. Stand structure variables such as basal area and stand density was obtained by performing an inventory of vegetation in the plot.

Data analysis Data were analyzed descriptively by taking into account of measurement results in the field. Descriptive statistical analysis was done to see the average and standard deviation of each of analyzed stemflow parameter. Paired t-test was conducted to analysis the differences of each stemflow parameter. The relationship between the rainfall depth and the stemflow depth was analyzed by making a regression equation in which the stemflow depth was independent variable and the rainfall depth was dependent variable.



Figure 1 Setting up the measurement tool of stemflow volume.

Results and Discussion

Daily rainfall Rainfall measurement results for 5 months provided the number of rainy days recorded as many as 75 days of rainy days, with daily rainfall interval range was 0.56–78.69 mm. Mean of daily rainfall during the study amounted to 18.40 ± 21.40 mm. Figure 2 shows that the rainfall was concentrated in less than 10 mm of daily rainfall. The results of the standard deviation calculation of daily rainfall measurements suggests that the daily rainfall data has a very high variability.

Stemflow yield Stemflow volume measured varies both on the same and the difference of land cover types. The stemflow volume (liter) and its relationship with rainfall depth for each plant of any measurable precipitation is presented in Figure 2. In general, oil palm plant produced stemflow much larger than other plants for the same rainfall. Oil palm plant was capable of producing stemflow volume of 7–15 times compared with plants on forest land cover type, and reached 12–24 times of stemflow volume of rubber plants.

Stemflow yield vary both between different species and between the same species. These were consistent with the results of the study of Crockford and Richardson (2000), Garcia-Estringana *et al.* (2010), and Galdos *et al.* (2012). This variability may occur due to differences in rainfall, plant conditions, and meteorological conditions (Levia *et al.* 2010). Absolute value of stemflow is the influence of the relationship between rainfall duration, rainfall intensity, and characteristics of plants (Garcia-Estringana *et al.* 2010). The variability was caused by the difference among the biophysical characteristics of tree species, including the size of the canopy, leaf shape and orientation, angle branches, and bark roughness (Levia & Herwitz 2005). The large volume of water flowing through the trunk will have an impact on water potential which is capable to infiltrate into the soil (Herwitz

1986). The greater water to the soil surface is the greater potential for water that can be infiltrated into the ground. Li *et al.* (2009) stated that stemflow is conducive to concentrate and keep the water in the deeper soil layers. Thus, if the water volume that reached the ground surface exceeds the infiltration capacity of the soil, water reaching the soil surface will be transformed into a run-off.

Stemflow depth Stemflow depth varied both on the same land cover type and among different land cover types (Table 1). Standard deviation results of stemflow depth data shows a great value, this means that the data have high variability. Results of paired t-test analysis showed that stemflows depth in forest and jungle rubber cover were significantly different. Stemflow depth in rubber plantation showed that R1, R2, and R5 were not significantly difference. R3 and R6 also were not significantly difference. Stemflow depth in oil palm plantation showed that OP2 and OP3 were not significantly difference.

Percentage of rainfall proportion as stemflow was not entirely depend on the diameter of the stem and canopy projection area (Figure 3), though there was a tendency that the larger stem diameter had the higher percentage of rainfall proportion as stemflow. R4 plants had large canopy projection area but smaller percentage of stemflow compared to other plants, while OP2 resulted in the largest stemflow. These results accorded with previous studies in which the average percentage of the stemflow was only 0.4% (Bahmani *et al.* 2012), 0.9–2.7% (Park & Cameron 2008), 0.1–1.5 % (Molina & del Campo 2012), and 0.3–1.4% in the natural tropical forests of Kalimantan (Asdak *et al.* 1998), so that in some analysis stemflow is often neglected.

However, the large volume of water generated by the stemflow must be taken into consideration of land management, especially of oil palm plantation. In oil palm

plantation, the stemflow volume scale up to the ground surface was large enough to trigger the surface run-off. In the same area, the stemflow of the oil palm plantation was distributed only by a few plants because the plant density was lower than other land cover types that have higher trees density. Consequently, the rainwater reaching the soil surface through the stemflow in oil palm plantations was concentrated at fewer collection points.

Rainfall has a close relation with the depth of stemflow although this relation varies for each plant. Regression analysis relationship between rainfall depth and stemflow

depth showed a tendency that the higher rainfall will increase the stemflow depth. The slope of the regression equation between rainfall depth and stemflow depth of oil palm plantation was much greater than logged forest, jungle rubber, and rubber plantation (Figure 4). This means that increasing of one unit of rainfall will lead to greater stemflow of oil palm plants than other plants.

The variability of stemflow depth were caused by the characteristic of canopy and stem. Variation in stemflow between species occurs because each plant has different

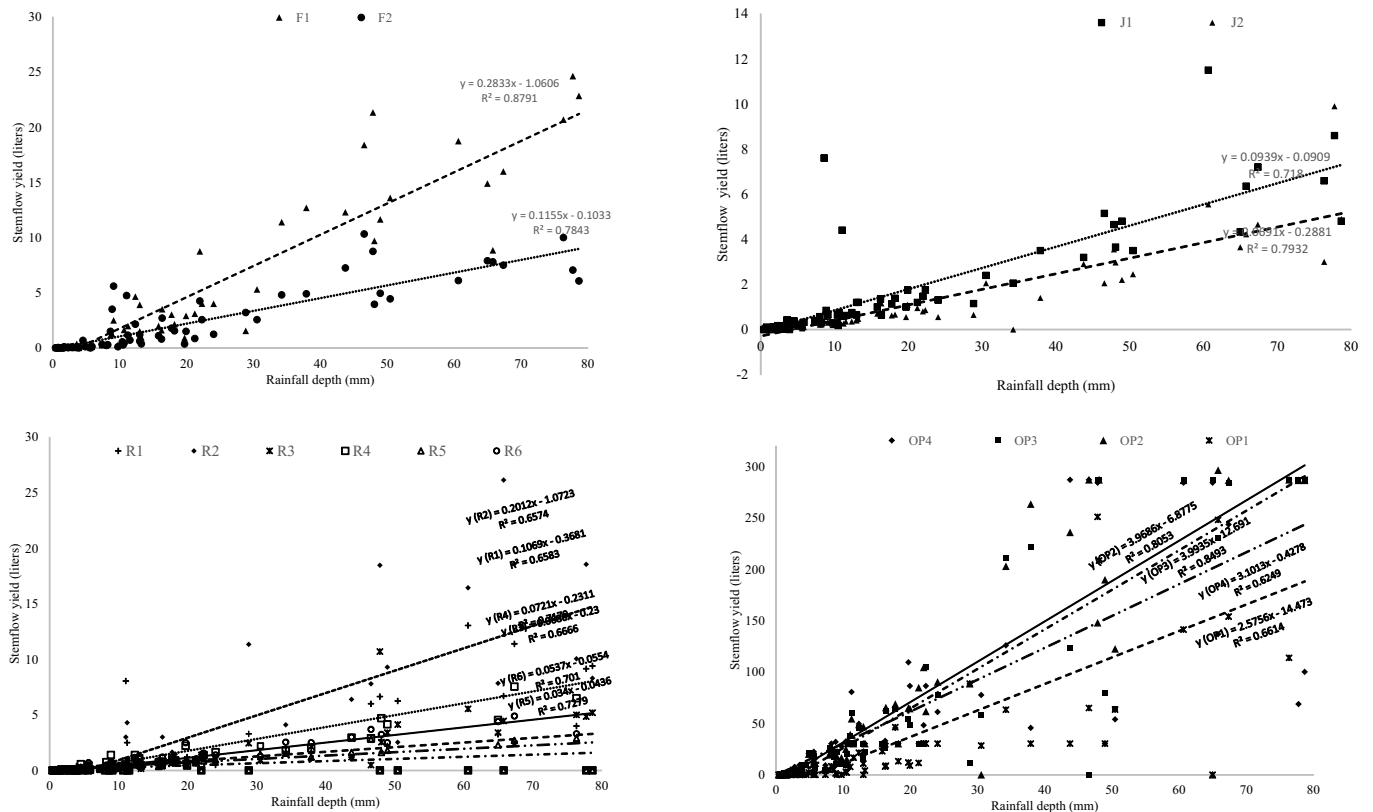


Figure 2 The results of stemflow volume measurements at each plant in every rainfall event.

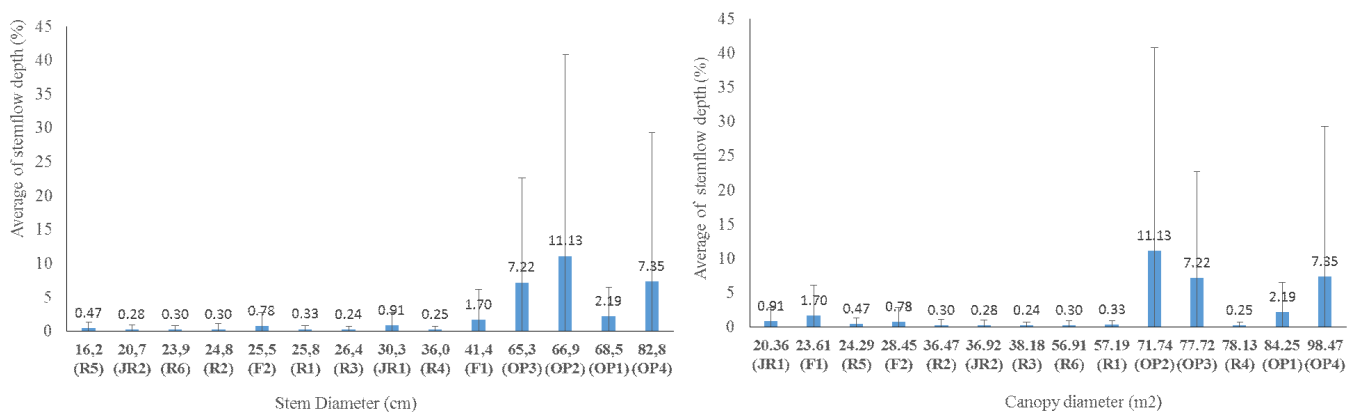


Figure 3 The average of percentage of stemflow depth based on stem diameter and canopy diameter.

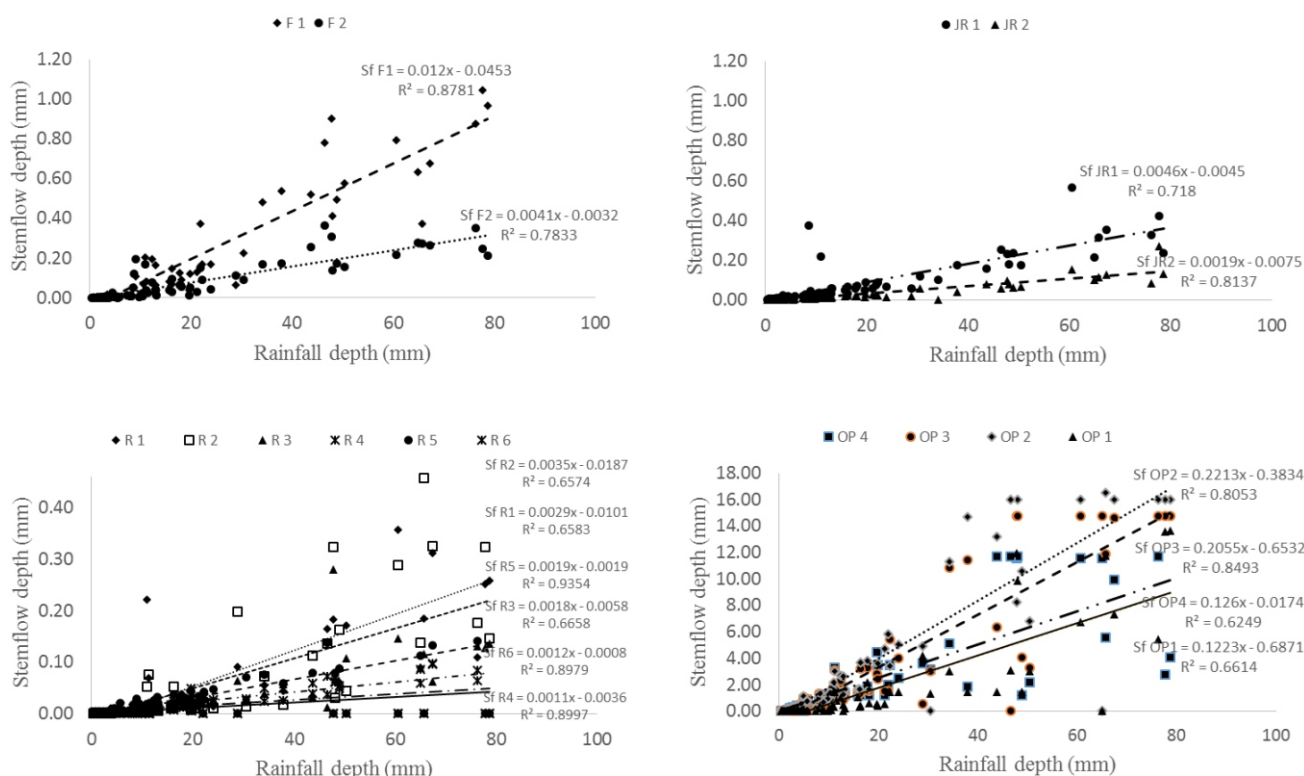


Figure 4 Regression relationship between rainfall depth (mm) and stemflow depth based on canopy area.

characteristics (Návar 2011). This variation depends on the plant and its rainfall characteristics. The straight stem and smooth bark will increase more stemflow than the crooked and rough stem. The amount of stemflow was also closely related to the diameter or trees basal area. Previous research showed that the greater basal area has the greater stemflow (Asdak *et al.* 1998).

Stemflow rate Stemflow rate showed considerable variation both on the same land cover type and between different land cover types (Table 1). The average of stemflow rate at each plant are presented in Figure 5. Paired t-test analysis showed that there was a statistically significant difference between plants in forest cover and between plants in jungle rubber. Stemflow rate in a rubber plantation is quite diverse, there were certain plant groups that were not significantly different. Stemflow rate in oil palm plantation showed that OP2 and OP3 were not significantly difference but others were significantly difference. The largest stemflow rate occurred at the oil palm plantation, while the smallest one occurred in rubber plantation. Rainfall events with a depth of 1 mm produced stemflow volume of 7.17 l of oil palm plant, but only 0.73 l in rubber plant. The oil palm plant have stemflow rate far greater than the rubber plant. Figure 5 shows that the standard deviation of the measurement results of stemflow rate was greater than its average except in plants of OP2, OP3, and OP4; its mean that stemflow rate has high variability.

Stemflow funnelling ratio (SFR) The SFR calculation results is presented in Figure 6 and paired t-test analysis is presented in Table 1. The results showed that oil palm plant group has a SFR value which was much larger than other plants. The greatest SFR was found on oil palm plant namely OP2 as amount of 6.79 and the smallest SFR is in the rubber plant of R4 with magnitude of 0.52. Plants of F1, R3, R4, and R6 have SFR average less than 1, indicates there is less water down to the stem becoming stemflow than rainfall on open area with equivalent diameter. SFR which is more than 1 indicates that the plant canopy drains water into the trunk. Paired t-test analysis showed that there was a statistically significant difference of SFR between plants in forest cover, however SFR in jungle rubber are not significantly difference. Stemflow rate in a rubber plantation showed that R1, R2, R5, and R6 were not significantly difference, while R3 and R4 were significantly difference. Stemflow rate in oil palm plantation showed that OP2 and OP3 were not significantly difference but others were significantly difference.

All fronds of oil palm canopy structure arranged toward the stem with shape of gutter like and its slope angle toward the trunk causes the bulk of the water from the canopy concentrating towards to the main stem. This resulted in the SFR of oil palm plant to be higher. In a big rainfall event, the effect of SFR is the concentration of rainfall in the stem bottom by stemflow mechanism, which in turn will increase the runoff coefficient (Charlier *et al.* 2009). The higher SFR

means the higher distribution of rainfall to soil surface accumulating in around plant trunks. Rubber plant with the lowest average value of SFR indicated the least accumulation of water through the stemflow of the plant, while at the oil palm plant, the accumulation of water occurred at the base of the stem. SFR is calculated from the volume of stemflow without considering the canopy surface area that raises this volume and also without considering plant adaptation (Garcia-Estringana *et al.* 2010). This leads to SFR variability in the same plant species despite having almost similar trunk diameter. Návar (2011) stated that stemflow of water affects reception at ground level 2–7 times compared with the conditions of open ground. It is mainly on plants that have SFR value over 1. Some other researchers reported varying SFR value of diverse plants in diverse environments (Carlyle-Moses & Price 2006; Li *et al.* 2009)

Plant parameter Individual characteristics of plants measured in the form of type, stem diameter, basal area, canopy projection area, stem bark, and conditions are presented in Table 2. Table 1 and Table 2 show that stem characteristics and SFR did not show a clear relationship. The results of this study indicate that the palm trees with trunks rough conditions have a greater SFR compared with plants of forest cover with the same stem conditions but with smoother skin. On the contrary, the increasing bark thickness leads to absorption of water along stemflow pathways, reducing total stemflow volume (Levia & Herwitz 2005). The combination of rough bark and angular fronds creates funnelling waterways and also disrupts stemflow in addition to providing habitat for lichen and epiphytes (Link *et al.* 2004) that can be found in oil palm stem, which also have large water storage capacities. Marin *et al.* (2000) reported that the relationship between physical characteristics and stemflow

generation has been well documented in temperate forests, but contradictory results found in tropical forests.

Individual characteristics such as diverse plant can lead to variability in the results of stemflow. Canopy projection area associated with the surface area will capture rainwater that falls on the canopy. The higher extent of the canopy means the higher potential of rainwater that can be captured and flow through stem as stemflow. However, this study found that the canopy projection area was wider but the stemflow depth was lower than the plant with narrow canopy projection. This can be seen at stemflow depth of R4, whose canopy area was wider than R6, R1, OP2, and OP3 but its stemflow depth was lower (Figure 3). This is likely due to differences in density and thickness of the canopy. During the research, rubber plant shed leaves which resulted in canopy gaps, it reduced the capacity of canopy to retaining and flowing the rainfall to stem. Asdak *et al.* (1998) stated that stemflow correlated with physical characteristics such as tree diameter, basal area, and canopy projection area. Levia *et al.* (2010) stated that the difference in the size of tree trunks resulted effect on the outcome of the same species. Plants with large diameter are generally higher plants. Siles *et al.* (2010) suggested higher plants tend to have larger canopy projection area that can produce more stemflow volume. The results of this study indicate that the differences in plant characteristics such as stem diameter, basal area, canopy projection area, and trunks conditions produced various stemflow, however the relationship pattern between the stemflow and plant characteristics has not fully understood yet.

Although stemflow is almost always considered as a minor component of forest canopy water budgets as compared to interception and throughfall (Lorens & Domingo 2007), vegetation with high SFR must be

Table 1 The average of stemflow parameters and the results of paired t test

Plant	Stemflow depth (mm)	Stemflow rate l / mm (rainfall)	Stemflow funnelling ratio
F 1	0.18 ± 0.27 a	0.13 ± 0.13 a	0.95 ± 0.93a
F 2	0.07 ± 0.10 b	0.08 ± 0.10 b	1.54 ± 1.99 b
JR 1	0.08 ± 0.12 b	0.08 ± 0.11 bc	1.07 ± 1.49 ac
JR 2	0.03 ± 0.04 c	0.04 ± 0.02 d	1.15 ± 0.72 abcd
R 1	0.04 ± 0.08 d	0.06 ± 0.09 bce	1.14 ± 1.74 abcde
R 2	0.05 ± 0.09 d	0.07 ± 0.10 bcef	1.55 ± 2.06 bcdf
R 3	0.03 ± 0.05 ce	0.04 ± 0.03 dg	0.69 ± 0.59 j
R 4	0.02 ± 0.02 f	0.05 ± 0.04 efh	0.52 ± 0.35 k
R 5	0.03 ± 0.03 d	0.03 ± 0.02 degh	1.61 ± 0.77 befg
R 6	0.02 ± 0.02 ce	0.05 ± 0.03 efh	1.18 ± 0.63 abcdefh
OP 1	0.58 ± 0.85 g	0.83 ± 1.17 j	2.24 ± 3.18 bgh
OP 2	0.76 ± 1.18 h	2.38 ± 1.71 i	6.79 ± 4.88 i
OP 3	0.92 ± 1.33 h	2.07 ± 1.68 i	6.20 ± 5.02 i
OP 4	0.39 ± 0.80 i	2.33 ± 1.75 i	4.33 ± 3.25 l

Note : values followed by different letters indicate significant differences at $\alpha = 0.05$

considered in land management to increase soil water recharge and to decrease runoff. Oil palm plantations have little litter cover on the soil surface, with a high SFR value it will increase runoff due to low soil infiltrability (Banabas *et al.* 2008). In forest cover, stemflow reaching the forest floor is intercepted by the litter, the remainder flows into the mineral soil as forest floor leachate and produce small runoff. Implication of land management that can be performed in the oil palm plantation to increasing soil water recharge is making rorak. The use of rorak can reduce runoff. Rorak is clogged holes of a certain size are made in the field and parallel to the contour lines. Rorak function is to trap and absorb water into the soil as well as accommodate the sediments. Rorak also serves to accommodate the remains of

plants, such as weeds, pruned leaves or leaf litter.

Conclusion

The proportion of rainfall becomes stemflow various between 0.04–3.07% of the total rainfall that reaches the surface. The lowest percentage occurred in the rubber and the largest in oil palm plantations. The mean volume of stemflow varies from 0.68 ℓ in rubber (R5) until 64.53 ℓ in oil palm (OP2). Stemflow depth varied both among the same plants and in a different land cover. Stemflow depth increased with the increase of rainfall. The slope of the regression relationship between rainfall and stemflow lowest depths found in rubber and the highest found in oil palm. Variability is also found in stemflow rate, where every 1 mm of rainfall

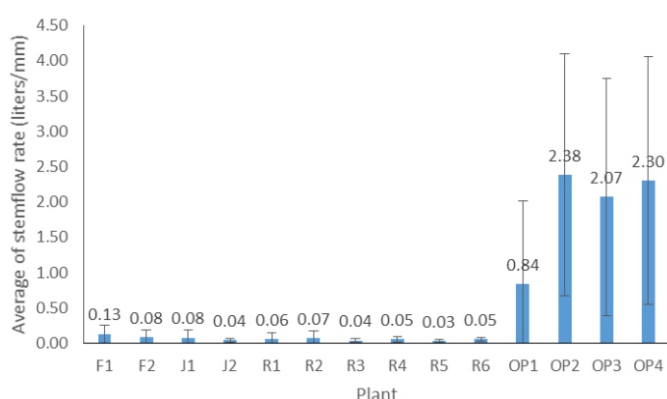


Figure 5 The average of stemflow rate at each plant.

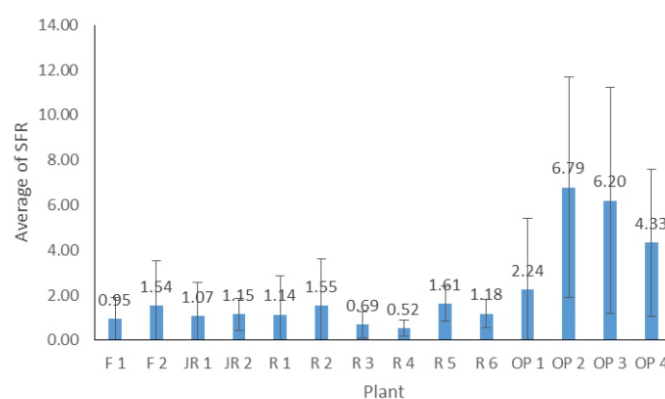


Figure 6 The results of SFR measurements at each plant.

Table 2 Plant characteristic of which stemflow was measured

Land cover	Tree/ oil palm	Species	Dbh (cm)	Basal area (cm ²)	Canopy projection area (m ²)	Stem condition	Stem bark condition
Forest	F1	<i>Litsea</i> sp.	41.4	1,346	23.6	Straight	Fine
	F2	<i>Litsea</i> sp.	25.5	5,100	28.5	Straight	Fine
Jungle Rubber	JR1	<i>Hevea braziliensis</i>	30.3	721	20.4	Rather slope	Rather rough
	JR2	<i>Macaranga</i> sp.	20.7	336	36.9	Bent	Fine
Rubber plantation	R1	<i>Hevea braziliensis</i>	25.8	523	36.5	Slope	Rough
	R2	<i>Hevea braziliensis</i>	24.8	482	57.2	Straight	Rather rough
	R3	<i>Hevea braziliensis</i>	26.4	547	38.2	Bent	Rough
	R4	<i>Hevea braziliensis</i>	36.0	1,017	78.1	Straight	Rather rough
	R5	<i>Hevea braziliensis</i>	16.2	206	24.3	Rather slope	Rough
	R6	<i>Archidendron pauciflorum</i>	23.9	448	56.9	Bent	Fine
Oil Palm Plantation	OP1	<i>Elaeis guineensis</i> Jacq	68.5	3,680	84.3	Straight	Rough
	OP2	<i>Elaeis guineensis</i> Jacq	66.9	3,511	71.7	Straight	Rough
	OP3	<i>Elaeis guineensis</i> Jacq	65.3	3,346	77.7	Straight	Rough
	OP4	<i>Elaeis guineensis</i> Jacq	82.8	5,382	98.5	Straight	Rough

can cause various stemflow between 0.73–7.17 ℓ respectively on rubber tree and oil palm. SFR parameter also showed high variability both among plants at the same landcover and at the different landcover. The result showed that stemflow variability was influenced by rainfall factor and plant characteristic, even though the relationship between plant characteristic and stemflow has not fully understood yet. Although stemflow is almost always considered as a minor component of forest canopy water budgets as compared to interception and throughfall but vegetation with high SFR must consider in land management to increase soil water recharge and to decrease runoff.

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